Design of a Centering Control System for Precision Measurement of Bearing Rings

Presentation to PMRC
Industrial Advisory Board

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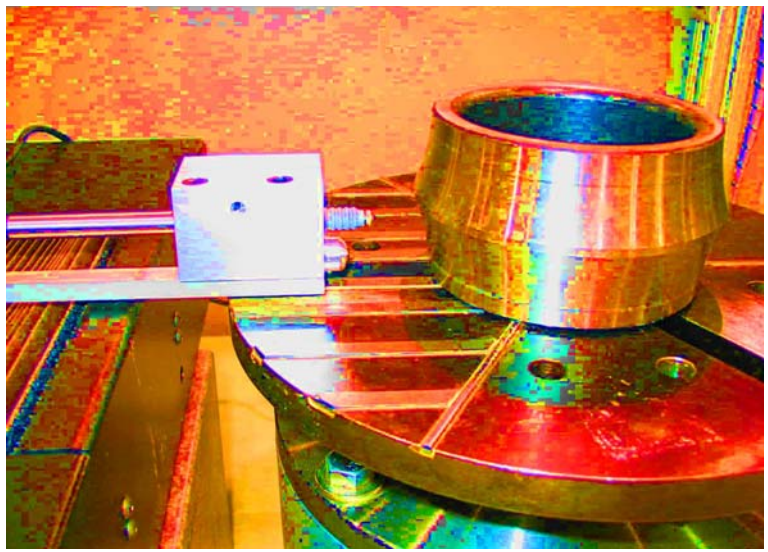
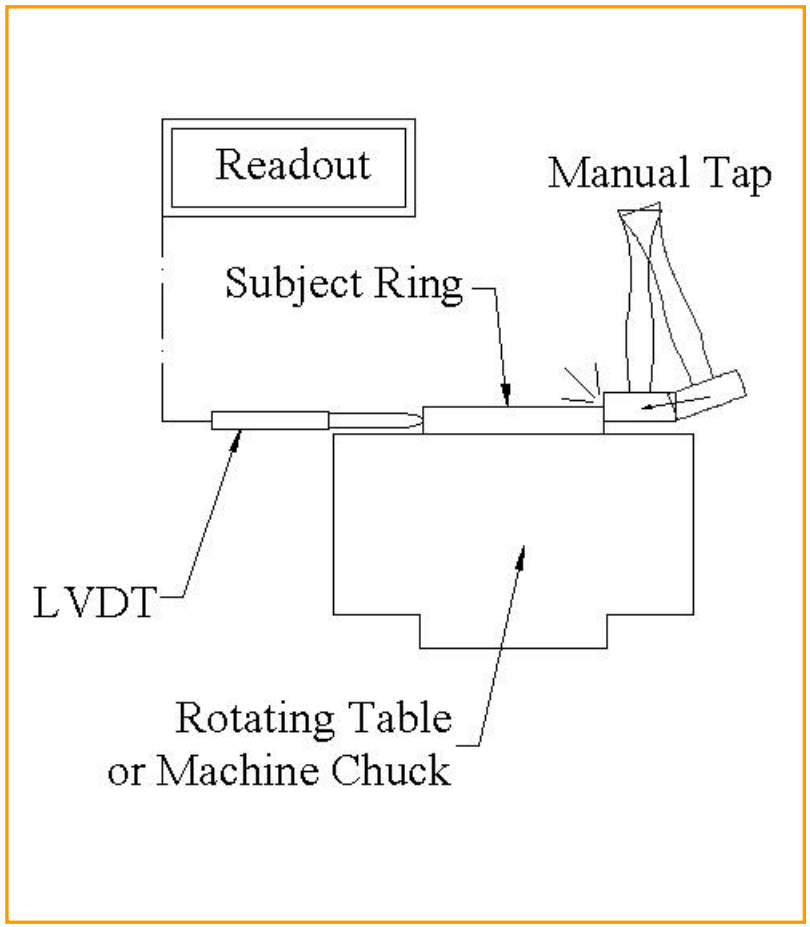


My Background

- BSME Virginia Tech 1993
- 7 years at SKF (bearing manufacturing)
- 4 years at Hitachi (automotive component manufacturing)
- MSME Georgia Tech 2001 (Distance Learning)
- Began full-time Ph.D. study in January 2004

Motivation

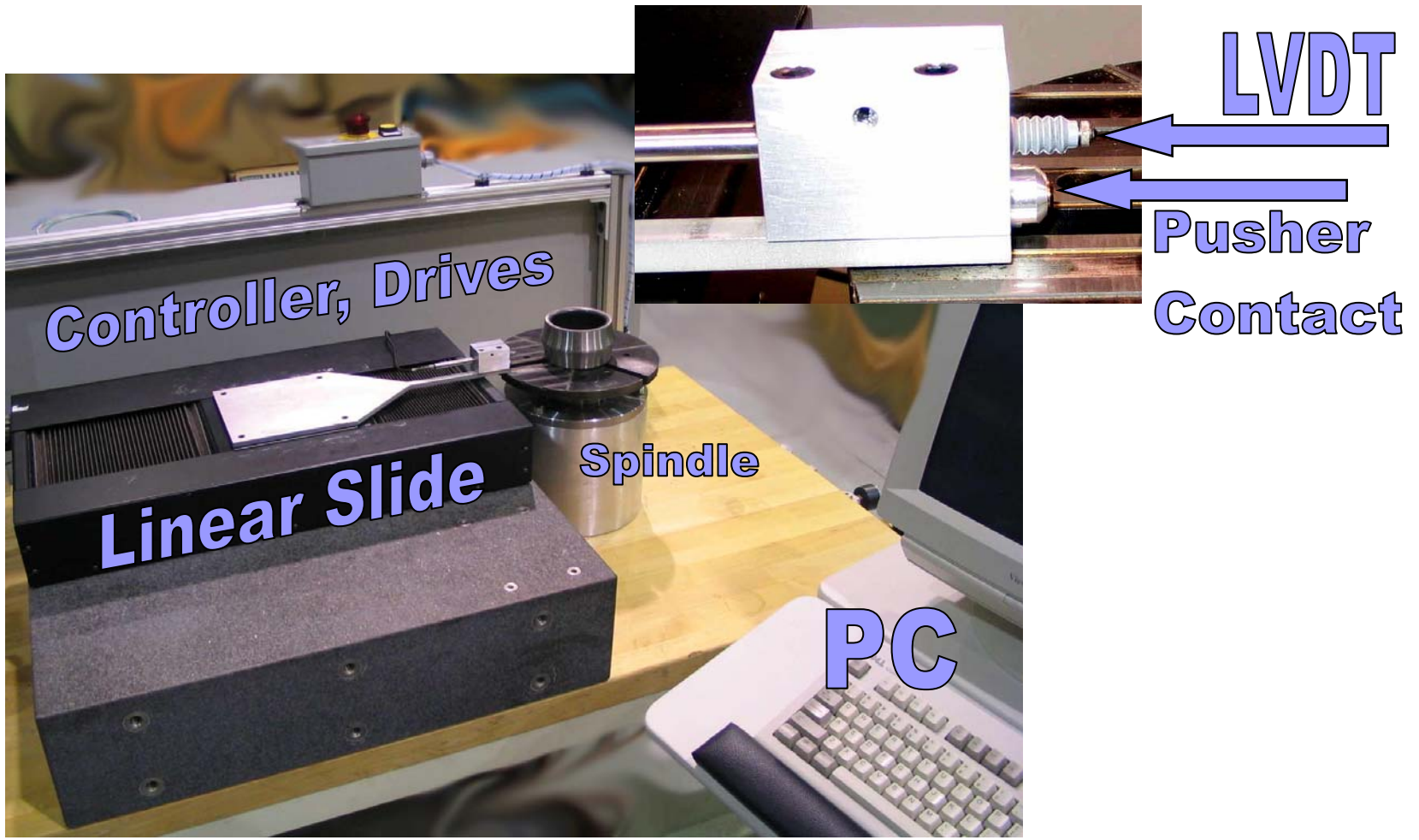
- Bearing rings are measured today in practice by placing on a rotating plate and centering manually
- Feedback loop is through operator's eyes on an LVDT digital readout
- Typical time to center a part within the 2.5µm tolerance window is one minute
- Problem =
  - high cost (manual labor)
  - low throughput
- Solution = automation



Primary Research Objectives

- Create a mechanistic model of ring system
  - Mathematical friction and stiction model
  - Inertial and flexibility effects
  - System response identification
- Develop an actuation method to move ring
- Develop an adaptive control algorithm to read ring position and actuate to center it
  - algorithm will need to learn from results of previous actuations
- Parametrize the model and algorithm to encompass a family of similar ring sizes
- Success will be measured by some combination of time to center and achievable centering tolerance

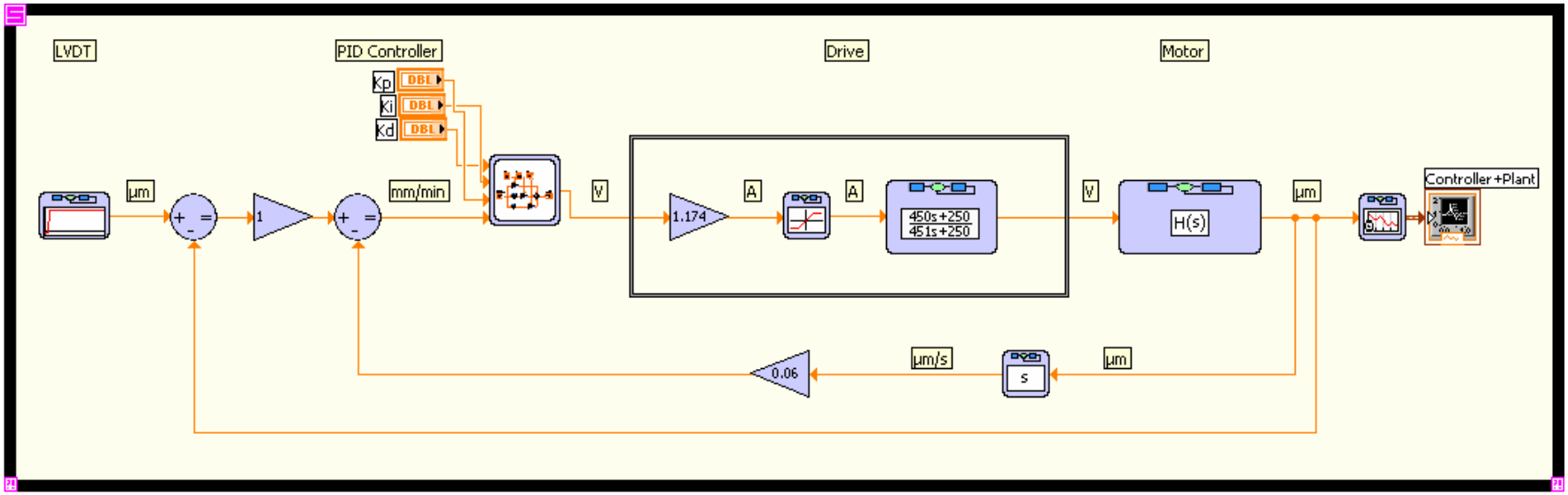
Prototype Plant Design



Research Plan - Modeling

- Create plant analytic model
- Build model through NI Simulation Module
- Validate and compare to actual physical response
- Develop controller and simulate behavior
- Validate controller + plant model
- Implement directly in hardware

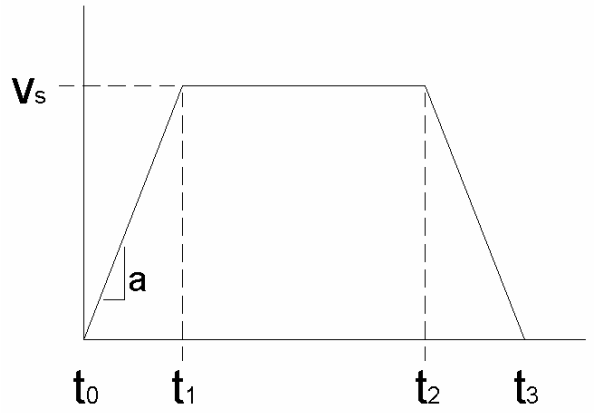
Initial Plant Model



- Tip position (LVDT – slide) commands slide velocity
- Identify motor model using NI SysID Toolset

Research Plan - Actuation

- Actuation Profile
  - *s* = distance to close following gap + off-center distance
  - Choose acceleration *a* and velocity v_s
- Trajectory Planning
  - Time to reach actuated position



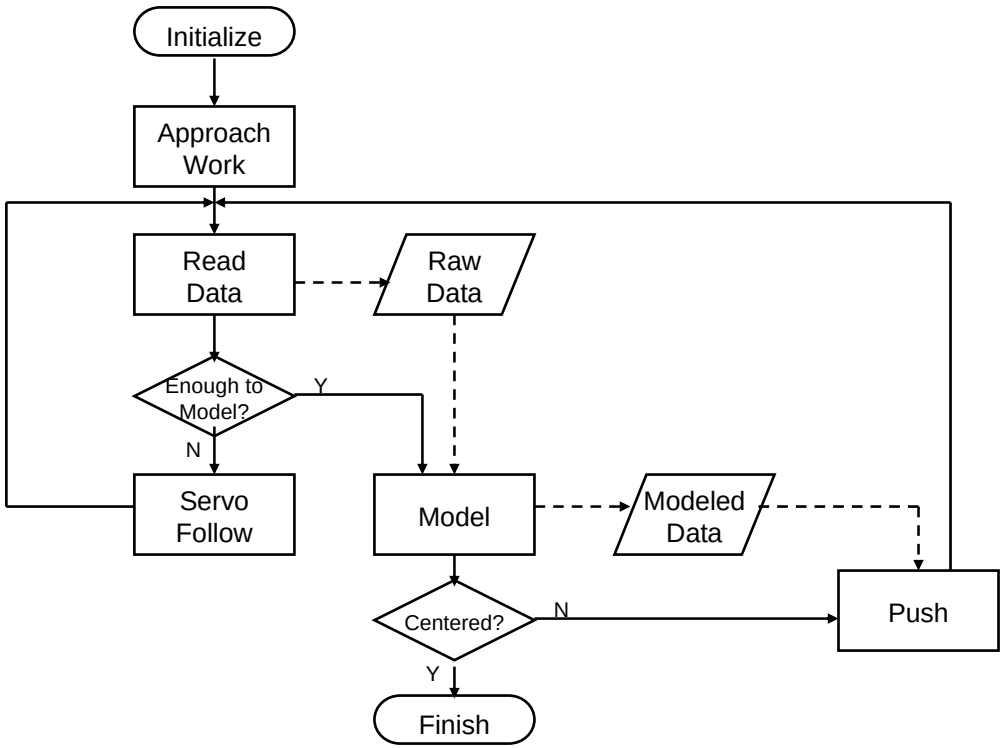
$$s = \int v dt = \int_0^{t1} a \cdot t dt + \int_{t1}^{t2} v_s dt + \int_{t2}^{t3} \left(a \cdot t_3 - a \cdot t\right) dt$$

$$t_3 = \frac{s}{v_s} + \frac{v_s}{a}$$

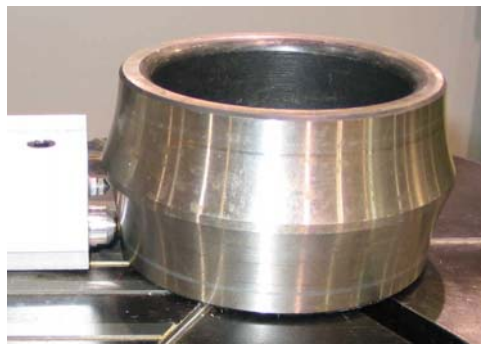
  - Begin actuation at spindle angle

$$L = \frac{360°}{2\pi} \cdot \omega \cdot t_3$$

Initial Algorithm

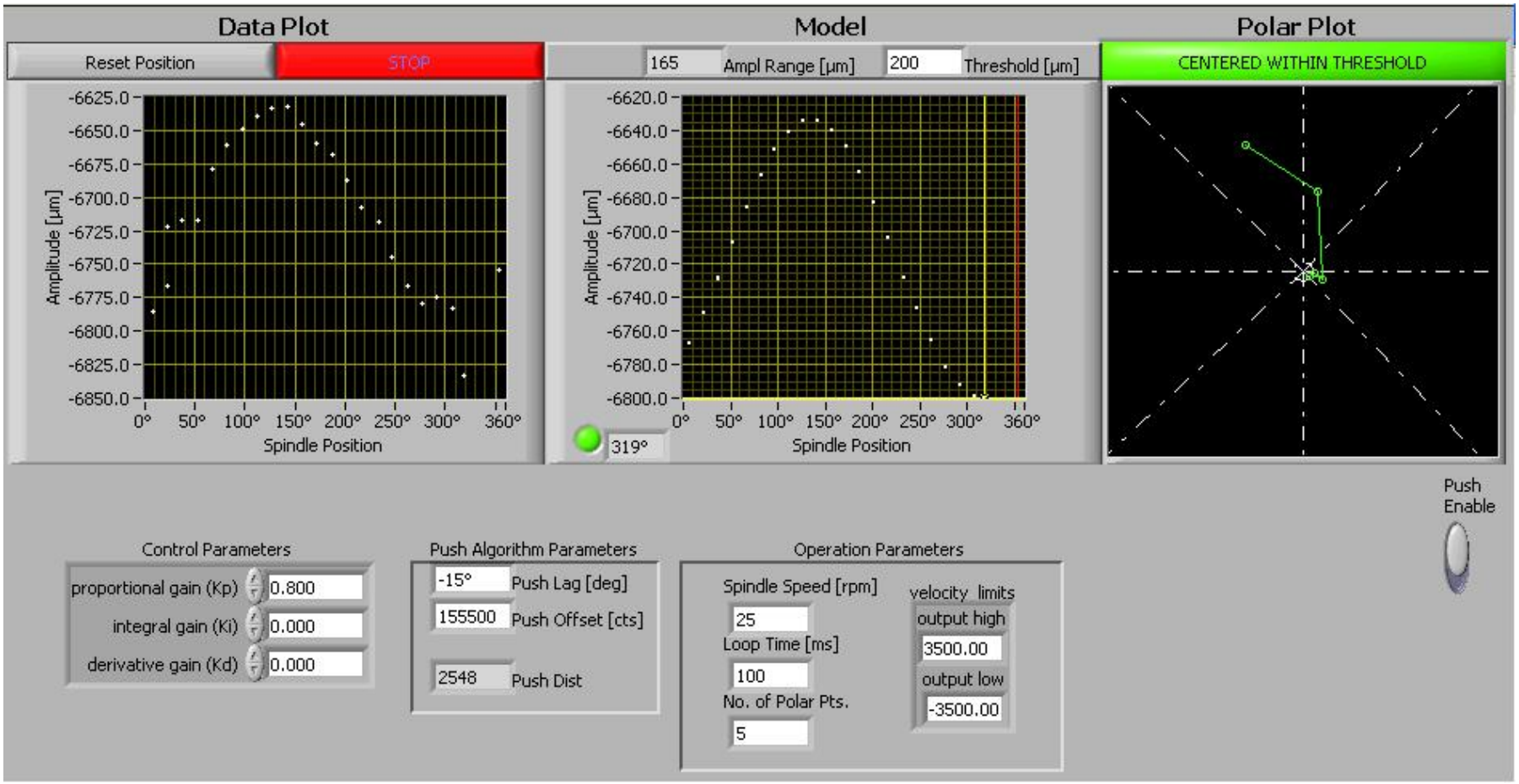


Following

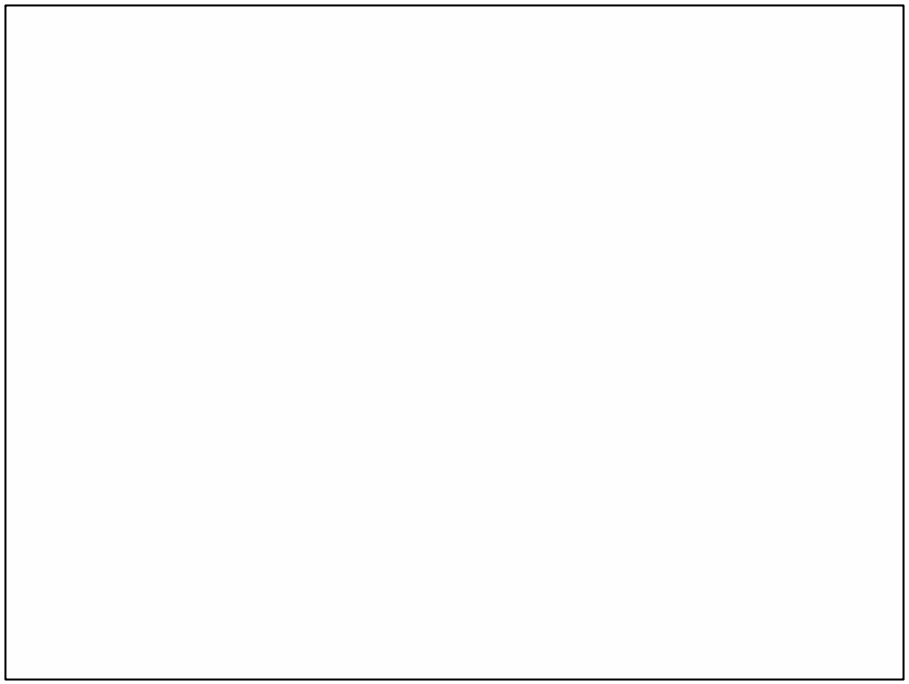


Pushing

User Interface



Operation



- Current capability is 10µm window in 1:30 (one part)
- Target is 2.5µm in 0:30 (adaptable 1lb - 150lb parts)

Research Plan - Parametric Extension

- Apply control model across different ring sizes
  - small gains to gently actuate light rings
  - big gains to overcome resistive force of heavy rings
  - what are the relationships?
- Establish relationships between ring parameters and model parameters
- Validate parametric model on new ring types
- May need to utilize piecewise model